

# Clean Energy Technology: American and Global Progress



Vail Global Energy Forum

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March 14, 2015

# Energy Market Dynamics

Global renewable industry growing, but faces challenges

Public policy evolving—mostly local

Unconventional gas a growing focus with geographic disparities

Infrastructure investments will be made, must focus on flexibility

Technology is creating a platform for disruptive change

Updated 3/13/2015

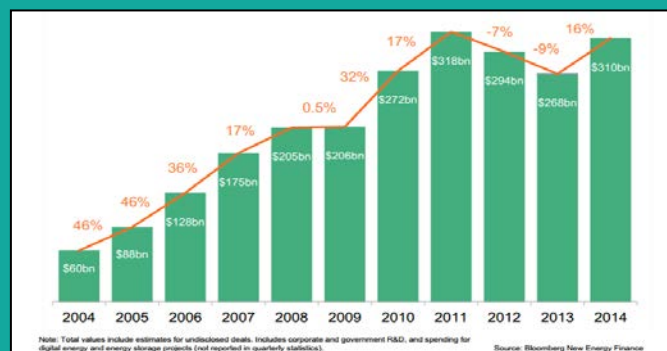
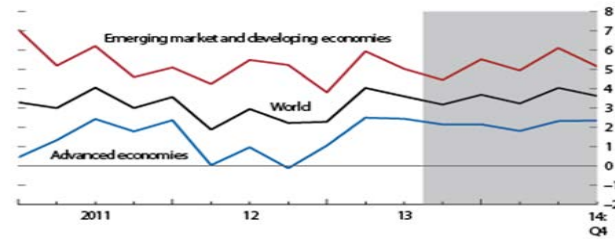


Figure 2. Global GDP Growth (Percent, quarter over quarter, annualized)



1.12 Natural gas spot prices



# A Profound Transformation is Required

## Today's Unsustainable Energy System

- Limited fuel diversity
- Subject to price volatility
- Inefficient and rigid
- Significant carbon emissions
- Delivery systems vulnerable
- Aging infrastructure

## TRANSFORMATION

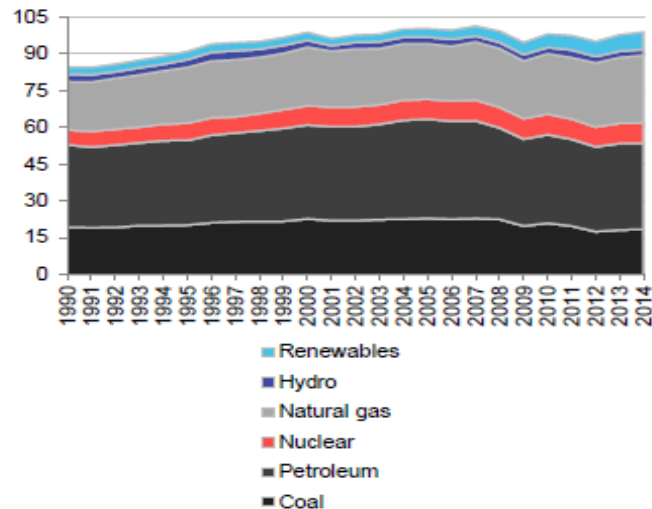
## Future Sustainable Energy System

- Diverse supply options
- Affordable, stable and reliable
- Efficient and flexible
- Carbon neutral
- Secure and resilient
- More consumer driven

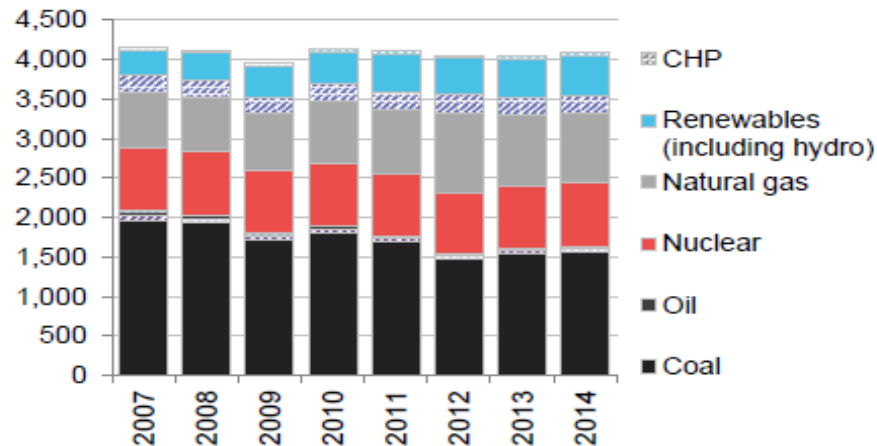
Updated 3/10/2015

# U.S. Consumption and Generation

US primary energy consumption by fuel type  
(Quadrillion Btu)



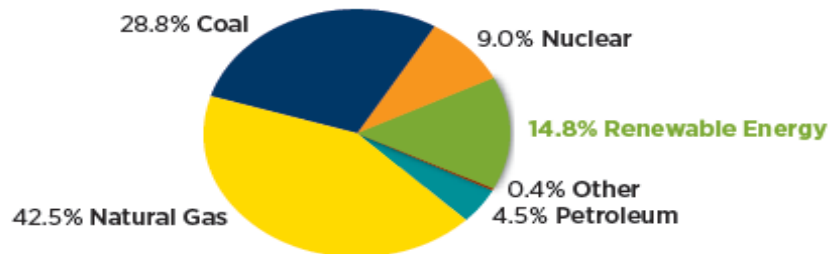
US electricity generation by fuel type (TWh)



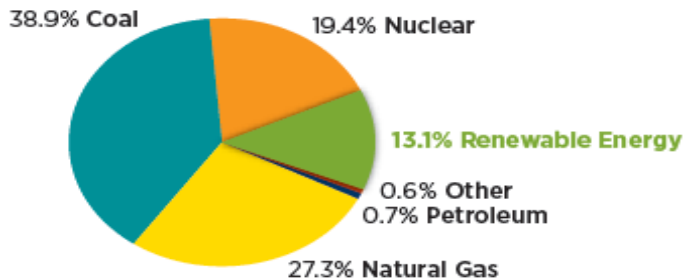
Source: <http://www.bcse.org/images/2015%20Sustainable%20Energy%20in%20America%20Factbook.pdf>

# U.S. Electricity Nameplate Capacity and Generation

U.S. Electric Nameplate Capacity (2013): 1,155 GW



U.S. Electric Net Generation (2013): 4,074 TWh



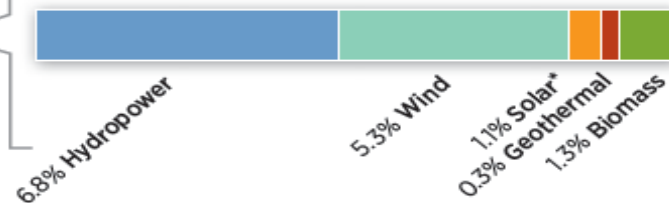
Sources: EIA, Larry Sherwood/Interstate Renewable Energy Council (IREC)

Other includes pumped storage, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, tire-derived fuels, and miscellaneous technologies.

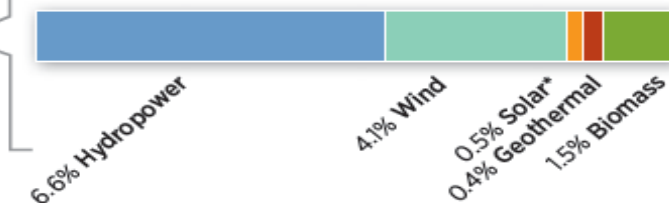
\*Grid-connected only

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U.S. Renewable Capacity: 171 GW

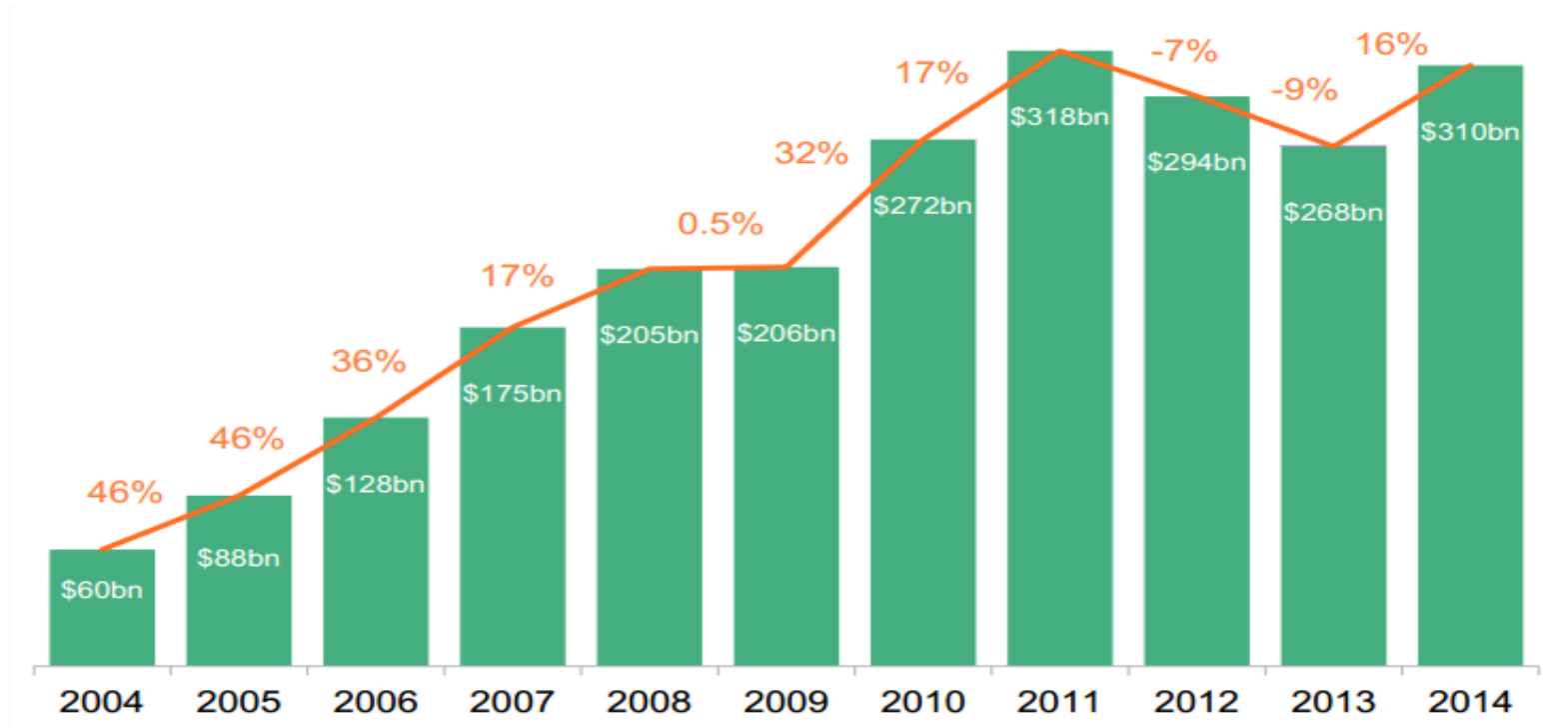


U.S. Renewable Generation: 534 TWh



Source: NREL 2013 Data Book

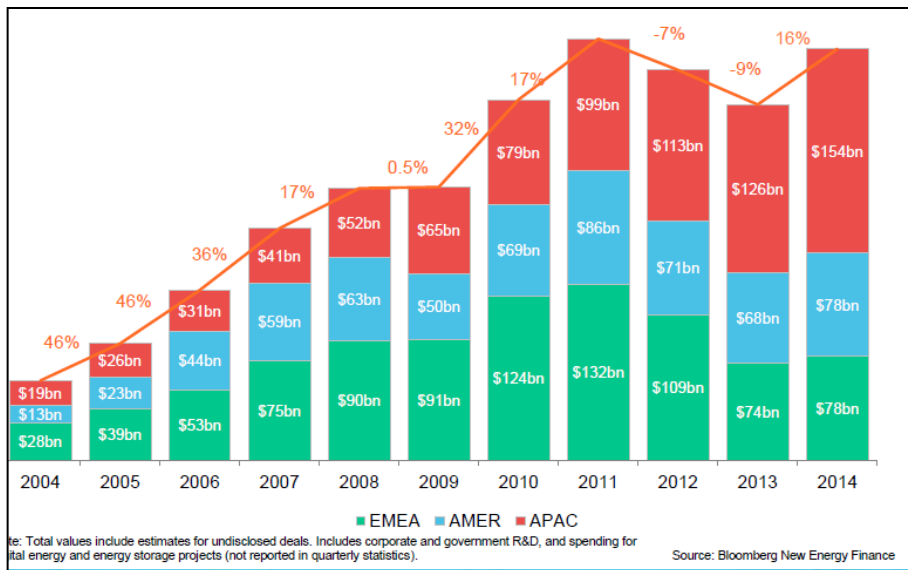
# Global New Investment in Renewables



Note: Total values include estimates for undisclosed deals. Includes corporate and government R&D, and spending for digital energy and energy storage projects (not reported in quarterly statistics).

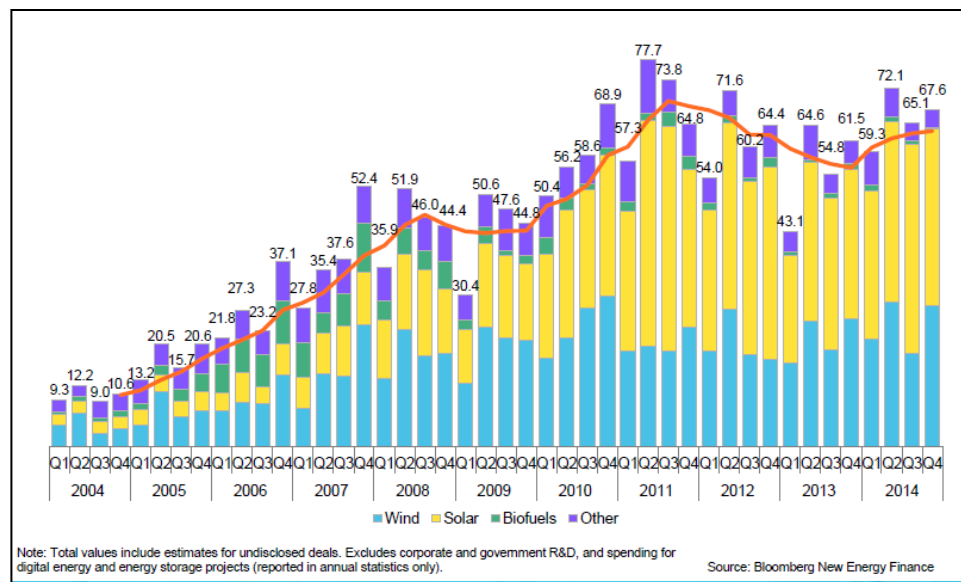
Source: Bloomberg New Energy Finance

# New Investment by Region and Sector



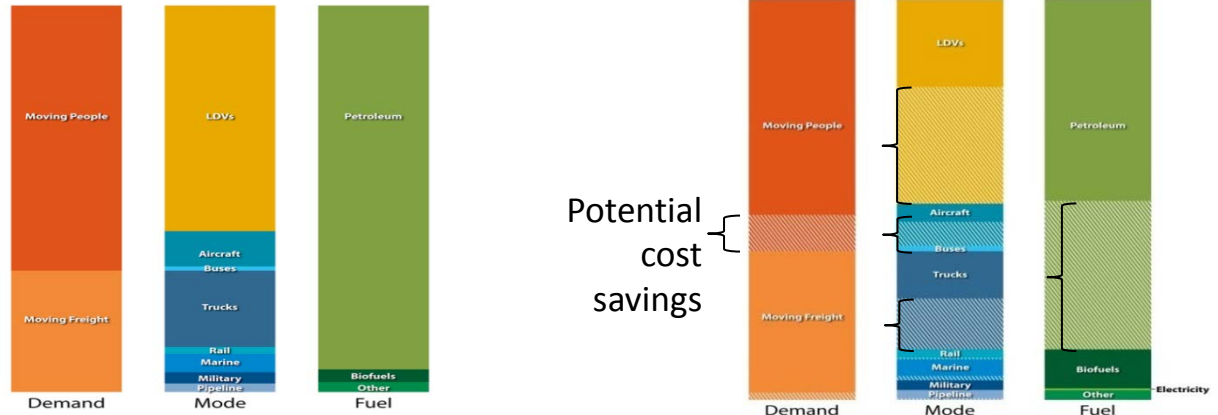
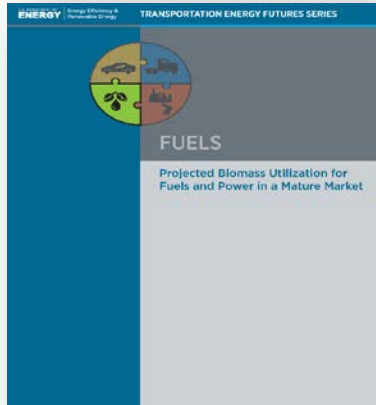
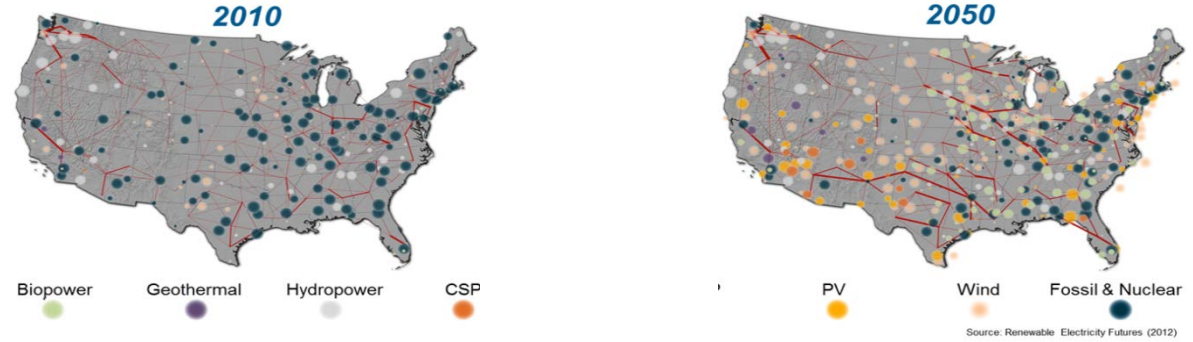
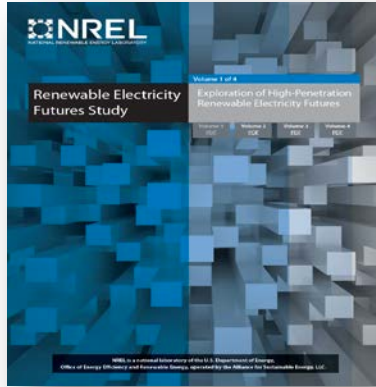
## New Investment in Clean Energy by Region

## New Investment in Clean Energy by Sector



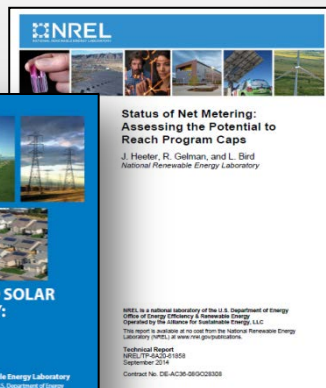
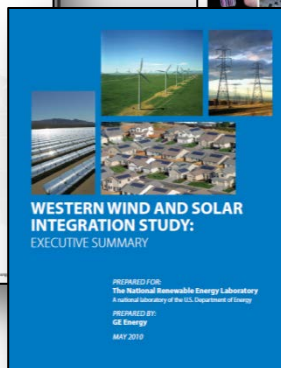
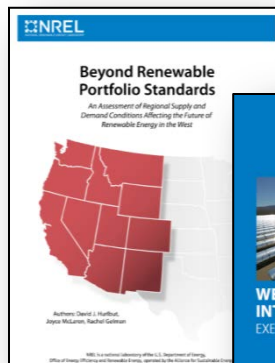
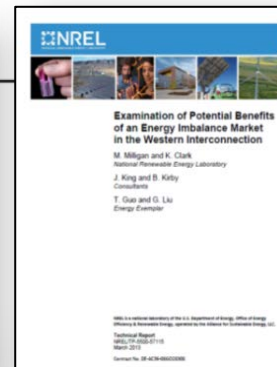
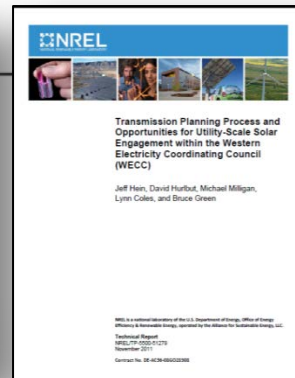
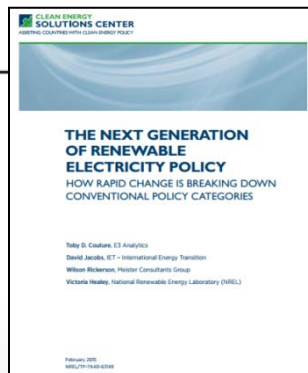
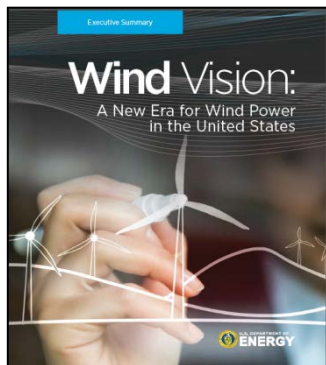
Source: <http://about.bnef.com/presentations/clean-energy-investment-q4-2014-fact-pack/content/uploads/sites/4/2015/01/Q4-investment-fact-pack.pdf>

# Comprehensive Studies Validate Aircraft Opportunity for U.S. Renewables





# Looking Toward Implementation



Benefits of distributed generation  
Economics of technical pathways  
Implications of high penetration renewables  
Value of regional cooperation



# Innovation, Integration, and Adoption

## Reducing Investment Risk

- Enable basic and applied clean energy technology innovation
- Accelerate technology market introduction and adoption
- Integrate technology at scale
- Encourage collaboration in unique research and testing “partnering” facilities

## Mobilizing Capital

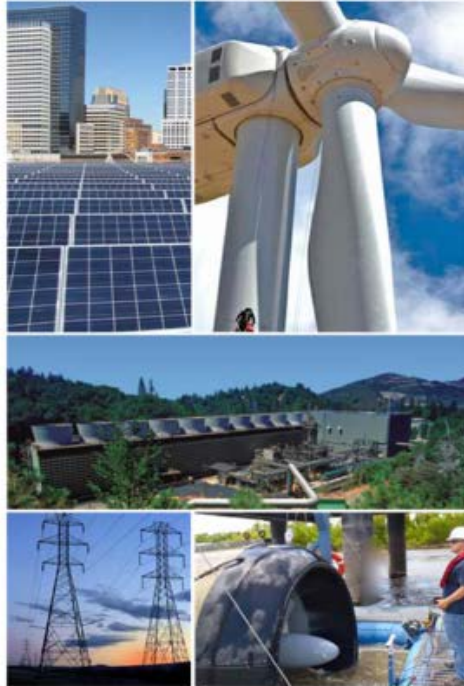


# Technology Innovation

## Sustainable TRANSPORTATION



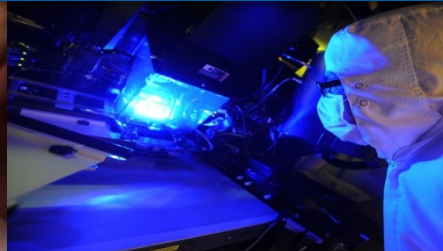
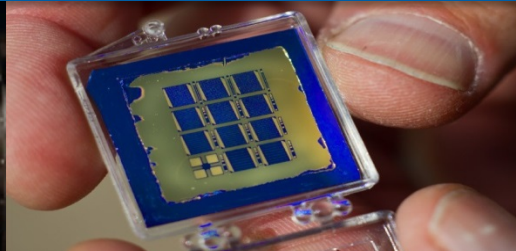
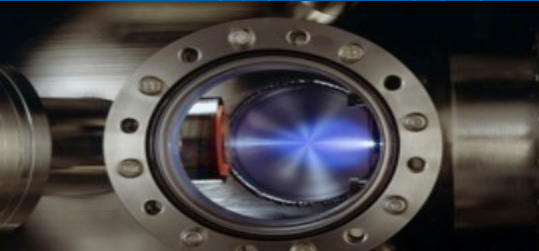
## Renewable ELECTRICITY GENERATION



## Energy Saving HOMES, BUILDINGS, & MANUFACTURING







## Market Impact

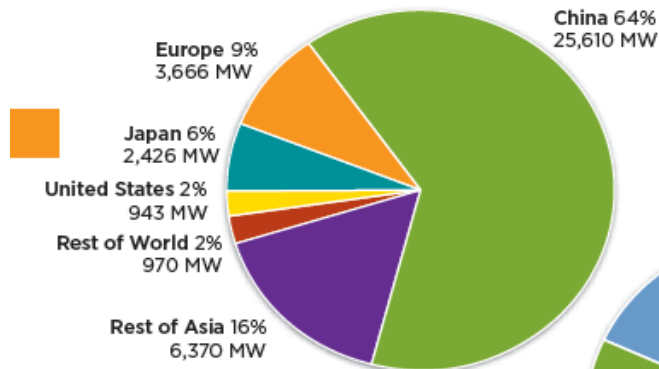
- **U.S. Capacity:**
  - 20 GW
  - <1% of U.S. power generation
  - <\$2 to \$6/W: LCOE 7 to 16¢/kWhr
- **Global Capacity:**
  - ~200 GW

Updated 3/10/2015

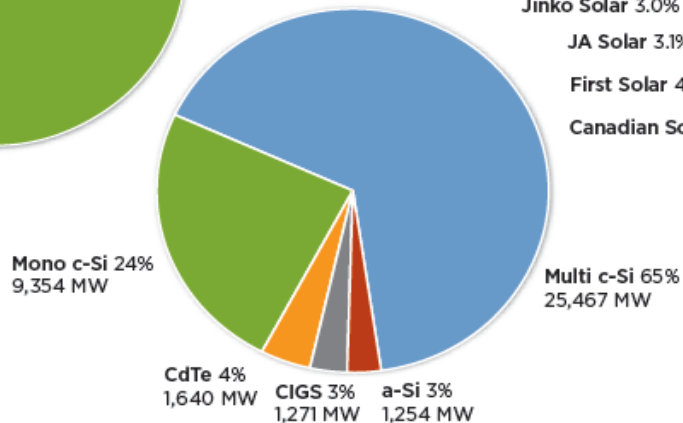
# Worldwide PV Manufacturing

Global Solar Module Production, 2013: 39,985 MW

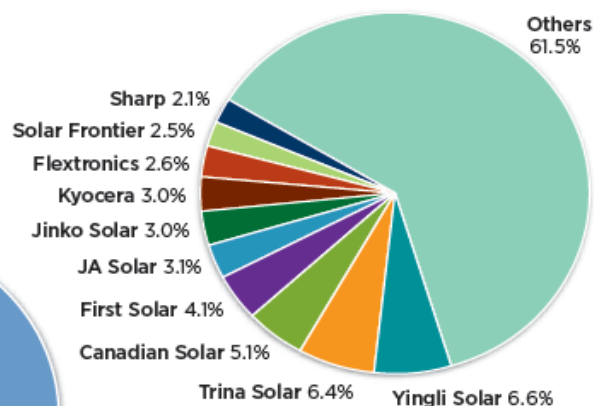
By Country



By Technology



By Manufacturer

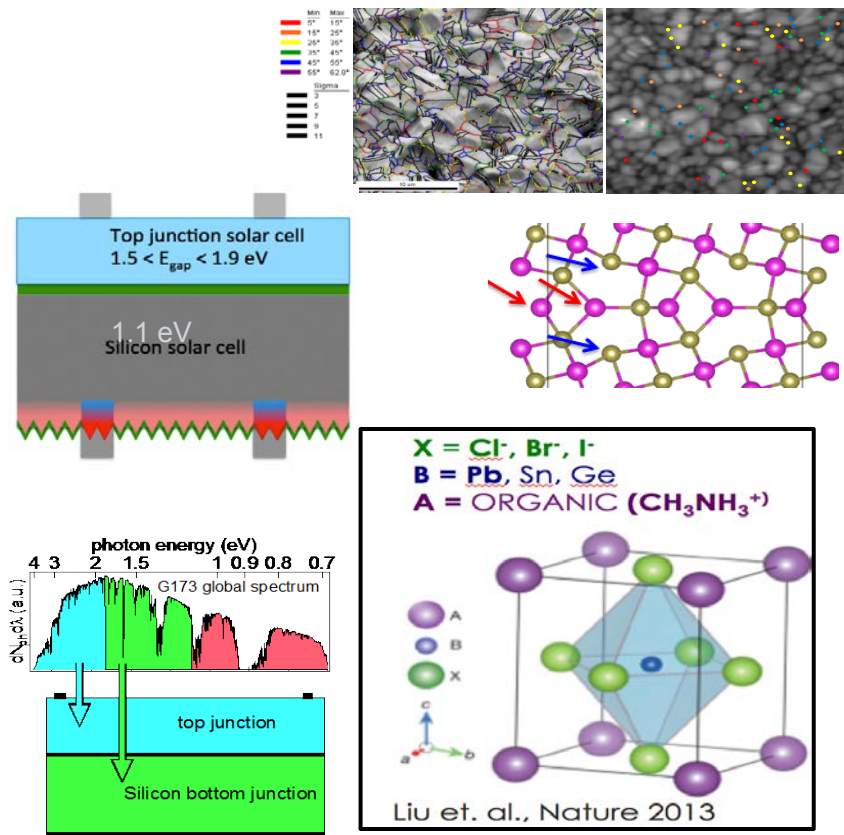


Source: GTM PV News, May 2014

Source: NREL 2013 Data Book

# PV Technologies

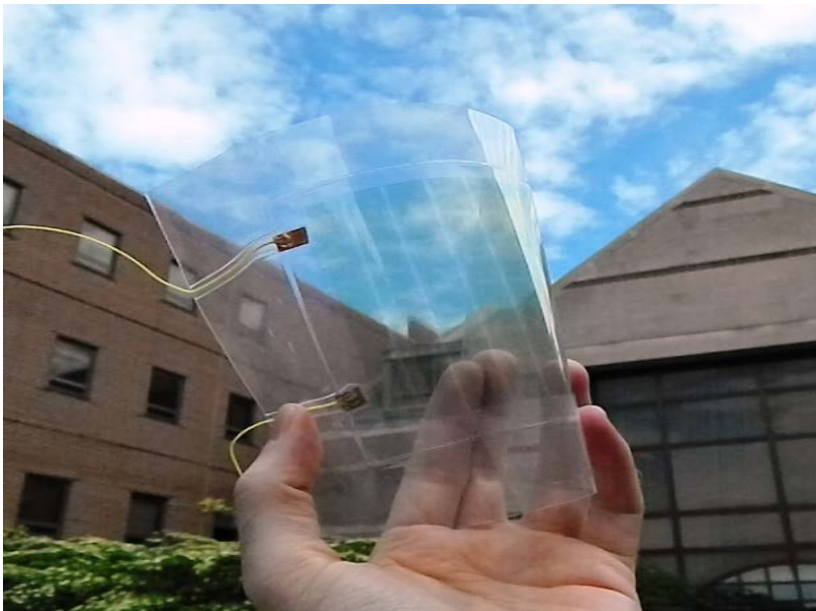
- High Efficiency Thin Films – Improved carrier lifetime and development of doping techniques will boost commercial module efficiency to 16%.
- Si Tandem Cells – Potential to increase the best cell efficiencies by 10%, to over 30%.
- Low Cost III-V 1J & 2J Cells – Potential to lower III-V growth cost by 1 – 2 orders of magnitude.
- “Kerfless Si” Wafers & Cells – Potential to cut supply chain capital investment by 50% with comparable cell performance.
- Perovskites – Very new polycrystalline thin film technology that has already demonstrated  $\eta > 17\%$ .





# **NSF Clean Energy Research: Optical and Nanostructural Control of Visibly-transparent Small-bandgap Excitonic Semiconductors For Integration in Highly-efficient Transparent Photovoltaics**

**Michigan State University, Award CBET- 1254662**



A transparent solar energy module that selectively captures infrared light is shown. These devices are creating a new paradigm and new markets for aesthetic solar energy harvesting

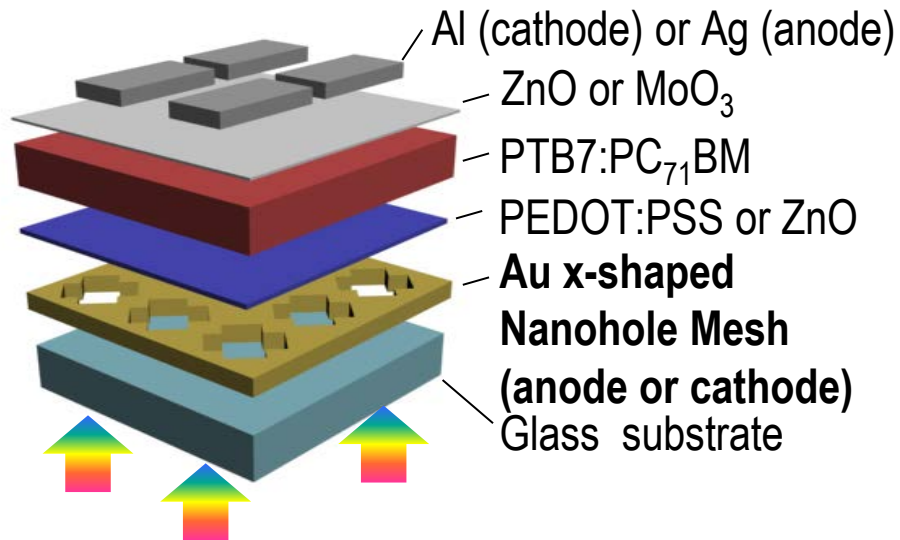


Art and Energy: High School Students use luminescent paints developed in our lab to paint colorful luminescent solar art paintings that can also generate electricity and inspire students in STEM

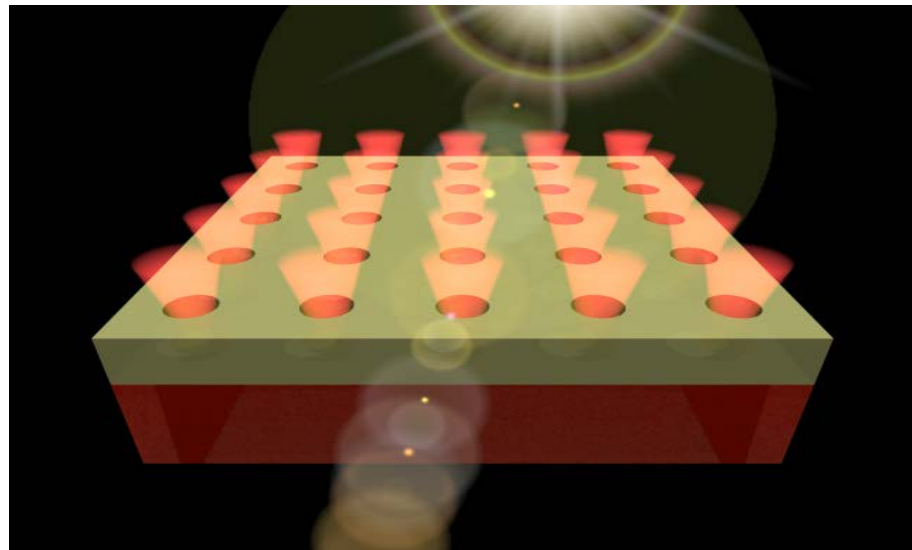




# NSF Clean Energy Research

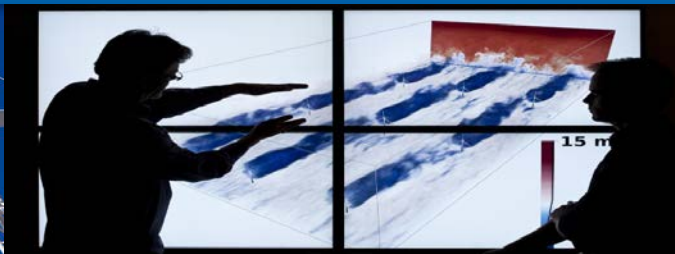
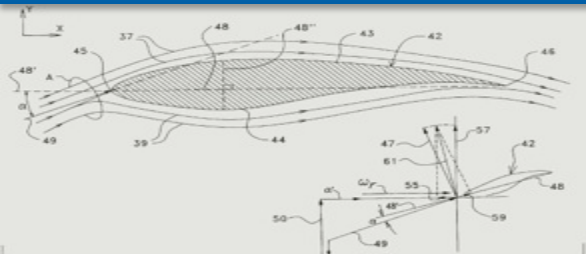


Plasmonic Wide Angle Light Concentrators for Bulk-Heterojunction Solar Cells [University of Washington, Award CBET- 1346859](#)



High Efficiency Photovoltaics Through Engineering Spontaneous Emission [University of Maryland, Award CBET- 1335857](#)



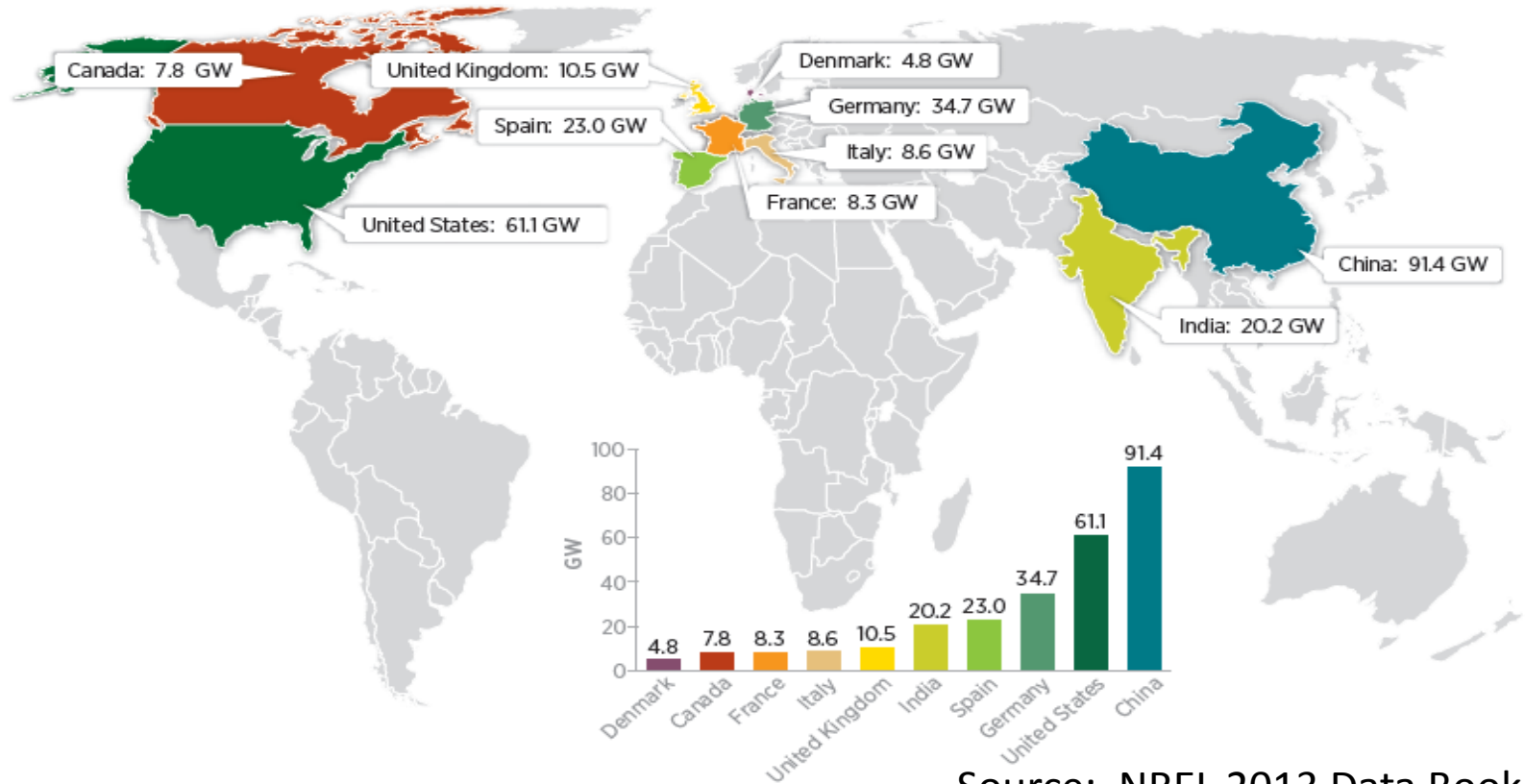


## Market Impact

- **U.S. Capacity:**
  - 66 GW
  - 3-9 cents/kWh
  - Installed cost: \$1.00-\$1.90/W
- **Global Capacity:**
  - 370 GW

Updated 3/10/2015

# Cumulative Wind Capacity – Top 10 Countries



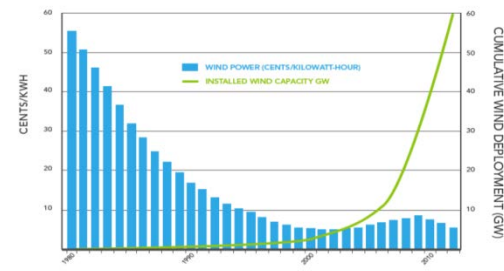
Sources: LBNL, REN21  
Includes offshore wind

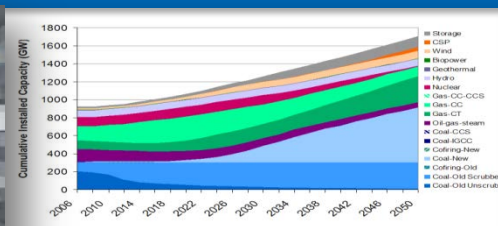
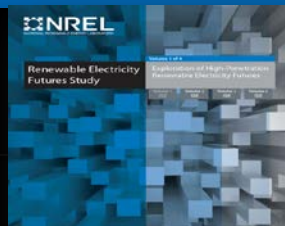
Source: NREL 2013 Data Book

# Wind Technologies

## DOE Thrust: Atmosphere to Electrons

- Wind farm system improvements
- Component improvements
  - Modular large components – blades, drivetrains, and tall towers
  - Advanced drivetrain power conversion systems
  - Flexible, ultra-large rotors and systems
  - Active controls for structural load reduction, improved wind plant performance, and grid-friendly operation



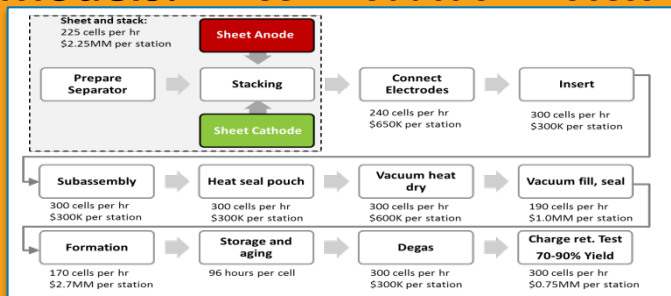


## Knowledge in Context for Decision Makers

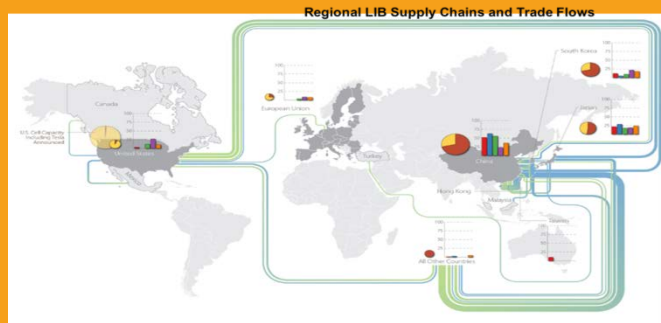
- **Techno-economic analyses identify R&D areas with high potential for impact**
- **Collaboration across national labs in support of the Quadrennial Energy Review (QER)**
- **Technical Assistance to FEMA and States in Rebuilding Following Weather Events/Disasters**
- **Analyses and Technical Knowledge Reduces Risk in Federal Investments**
  - Treasury 1603 Grants (Technical review of 98,816 clean energy projects to date, with \$23 billion in funding)
  - Navy-NREL Joint Technology Demonstrations in Hawaii and Guam (direct, recurring annual savings of 1 GWh)
- **Joint Institute for Strategic Energy Analysis (JISEA)**
  - Integrates capabilities across institutions
  - Provides analyses and information on clean energy in context of other energy pathways (fossil and nuclear)

# Clean Energy Manufacturing Analysis

## Technoeconomic Analysis – Detailed Cost Models: LIB Cell Production Process

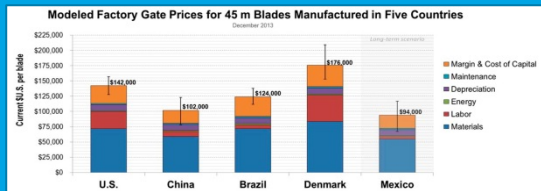


## Global supply chain assessment

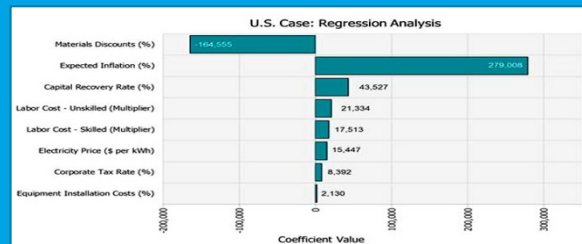


Chung, D.; Elgqvist, E. (2015). Automotive Lithium-ion Battery (LIB) Supply Chain and U.S. Competitiveness Considerations. NREL Report *in press*.

## Comparative cost analysis



## Sensitivity analysis



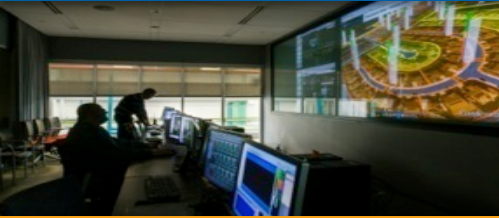
James, T.; Goodrich, A. (2013). Supply Chain and Blade Manufacturing Considerations in the Global Wind Industry (Presentation). NREL (National Renewable Energy Laboratory). 36 pp.; NREL Report No. PR-6A20-60063.

Goodrich, A. C.; Powell, D. M.; James, T. L.; Woodhouse, M.; Buonassisi, T. (2013). Assessing the Drivers of Regional Trends in Solar Photovoltaic Manufacturing. Energy and Environmental Science. Vol. 6(10), 1 October 2013; pp. 2811-2821; NREL Report No. JA-6A20-58652

James, T.; Goodrich, A. (2013). Supply Chain and Blade Manufacturing Considerations in the Global Wind Industry. NREL (National Renewable Energy Laboratory). 36 pp.; NREL Report No. PR-6A20-60063.



# NREL Research: Energy Systems Integration



## Early Impact

- New advanced inverters allow distributed generation to provide grid support
- Smart grid roll outs under ARRA
- IEEE Interconnection Standards
- 45 partners
- ~ \$20M level of effort





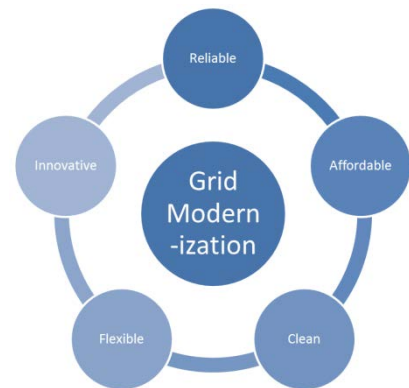
# The New Frontiers: Integration and Scale

- Integration of high-penetration renewables requires enhanced system-wide flexibility
  - Variable supply and variable load
  - Increased distributed resources
  - Enhanced energy imbalance market cooperation
  - Changing roles of consumers, utilities, investors, power providers, vendors, and regulators
- Regional considerations continue to drive progress
- Production scale and supply chain crucial to lower manufacturing costs
- Investment in technology R&D imperative
  - Better monitoring and measurements
  - Advanced analytics processing and control
  - Demand-shifting and load profile shaping techniques
  - Two way power flow control electronics





# Key Attributes of a Modernized Grid



## Sensing and Measurements

- Visualization tools that enable complete visibility of generation, loads and grid dynamics across the electric system

## Devices and Integrated Systems

- Establish common test procedures and interoperability standards for devices that can provide valuable grid services alone and/or in combination

## System Operations and Power Flow

- Develop advanced real-time control technologies to enhance the reliability and asset utilization of T&D systems

## Design and Planning Tools

- Create grid planning tools that integrate transmission and distribution and system dynamics over a variety of time and spatial scales

## Security and Resilience

- Develop advanced security (cyber and physical) solutions and real-time incident response capabilities for emerging technologies and systems

## Institutional Support

- Provide tools and data that enable more informed decisions and reduce risks on key issues that influence the future of the electric grid/power sector



# NREL + SolarCity and HECO

## TECHNOLOGY ADDRESSED

Interconnection challenges when connecting distributed PV into the electrical distribution grid such as in Hawaii (HECO).

## R&D STRATEGY

Inverters from various manufacturers will be tested at ESIF using NREL's unique power hardware-in-the-loop capability to evaluate system-level issues such as anti-islanding and volt-VAR support.

## IMPACT

Hawaii is moving towards 50% renewable energy and this project will work to improve the safety, reliability and stability of the electric power systems that include high levels of distributed PV.





**To achieve a  
clean energy  
vision, we must...**

**Invest in innovation**

**Invent the future we desire**

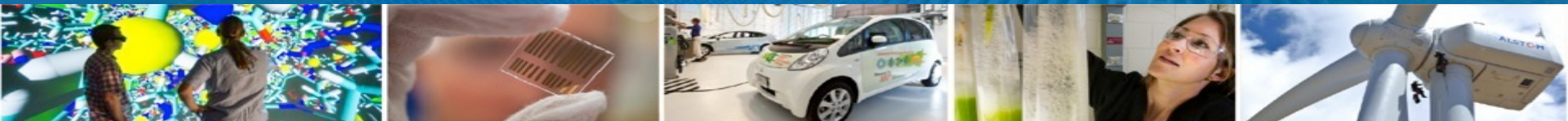
**Improve access to capital**

**Partner on a global scale**





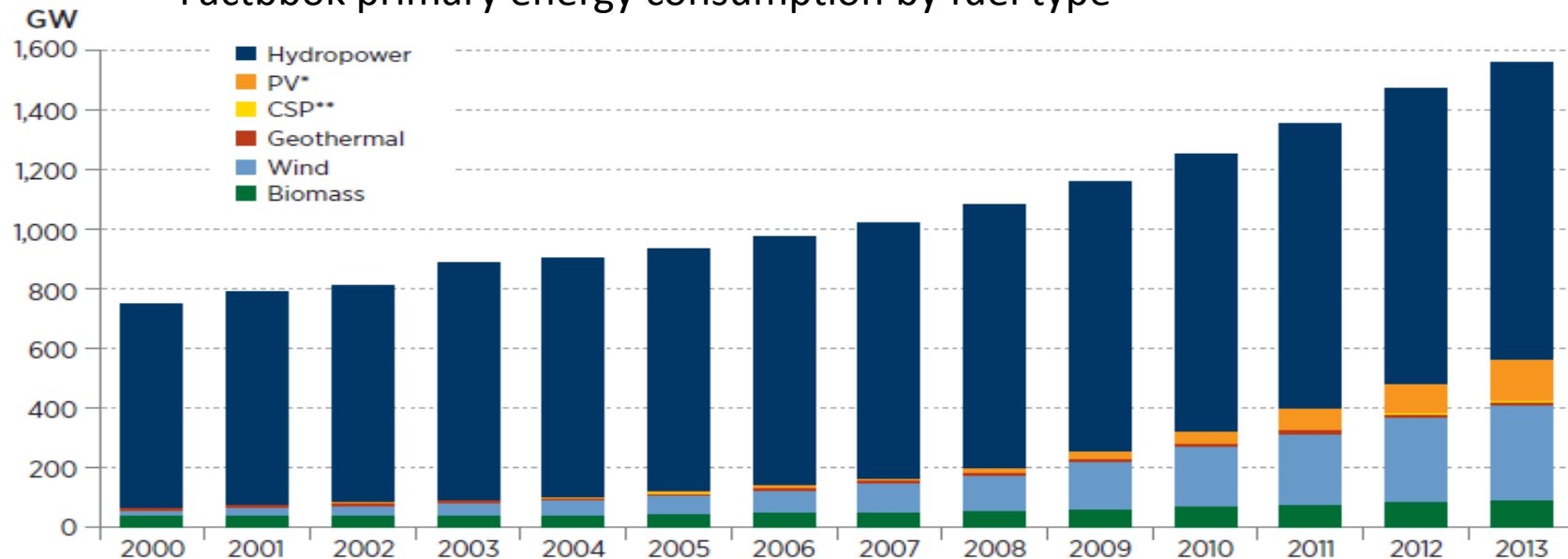
For more than 35 years, NREL has delivered innovation impact enabling the emergence of the U.S. clean energy industry.



For more information, please visit our website at  
[www.nrel.gov](http://www.nrel.gov)

# Global Renewable Electricity Capacity

Factbook primary energy consumption by fuel type



\*Grid-connected only

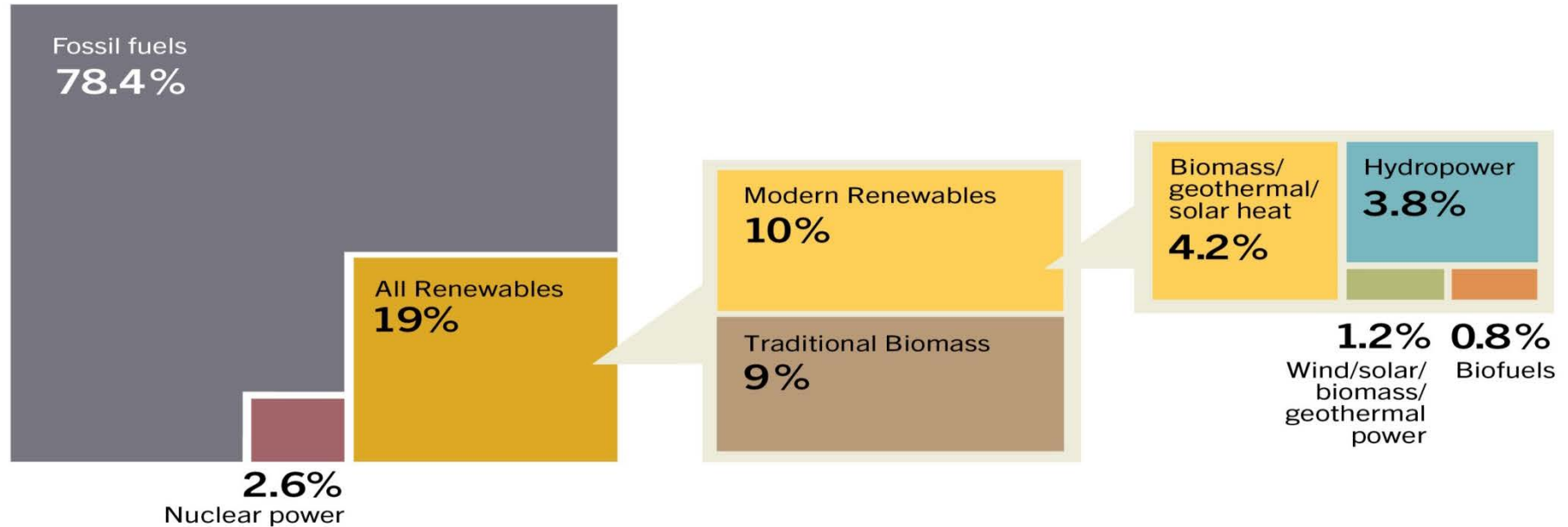
\*\*CSP includes Concentrated Photovoltaic (CPV)

Source: Renewable Energy Policy Network for the 21st Century (REN21)

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Source: NREL 2013 Data Book

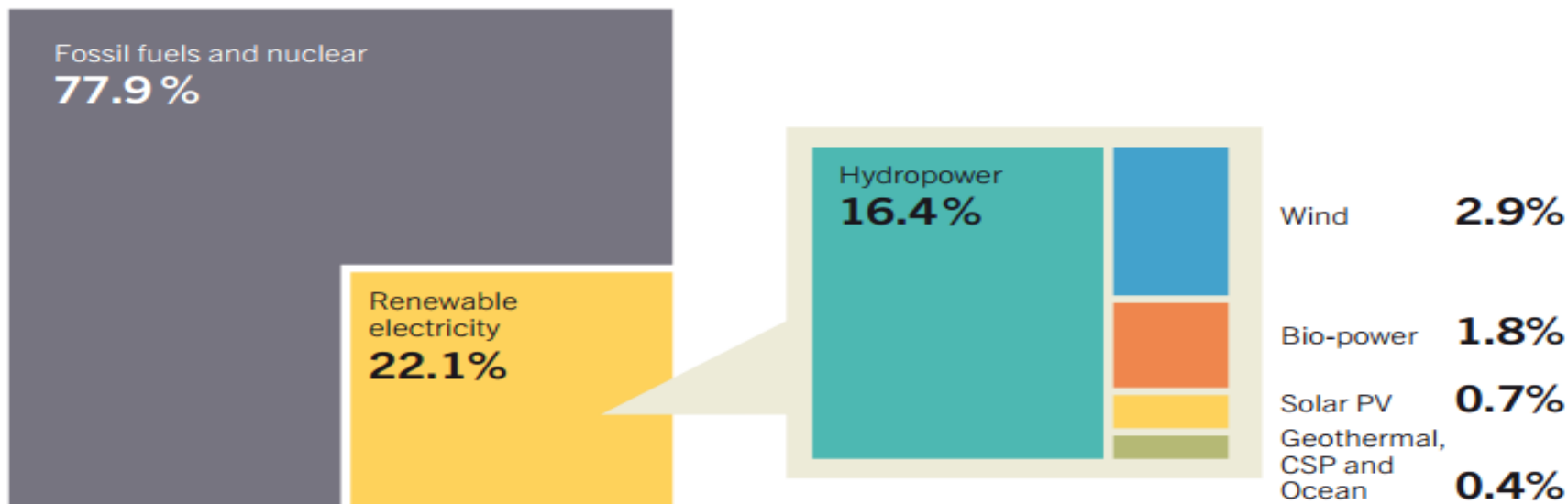
# Estimated Renewable Energy Share of Global Final Energy Consumption (year end 2012)



Source: REN21 Global Status Report 2014

[http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014\\_full%20report\\_low%20res.pdf](http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf)

# Estimated Renewable Energy Share of Global Electricity Production (year end 2013)



Based on renewable generating capacity in operation end-2013. Data do not add up due to rounding.

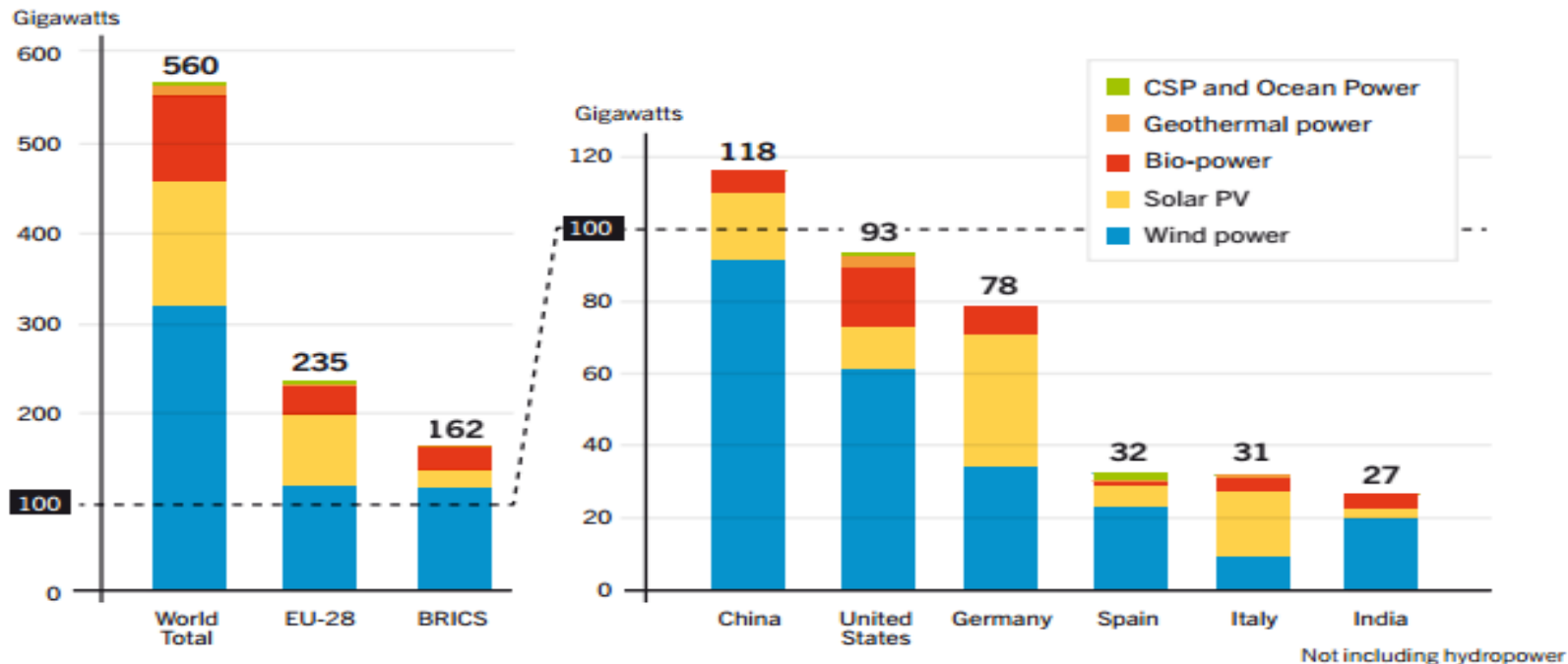
i - The GSR 2013 reported a global total of 990 GW of hydropower capacity at the end of 2012; this figure has been revised downward due to better data availability. This adjustment also affects the global figure for total renewable power capacity. In addition, global hydropower data and thus total renewable energy statistics in this report reflect an effort to remove capacity of pure pumped storage from the totals. For more information, see Methodological Notes, page 142.

Source: *REN21 Global Status Report 2014*

[http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014\\_full%20report\\_low%20res.pdf](http://www.ren21.net/portals/0/documents/resources/gsr/2014/gsr2014_full%20report_low%20res.pdf)

# Worldwide Renewable Power Capacity

Figure 4. Renewable Power Capacities in World, EU-28, BRICS, and Top Six Countries, 2013



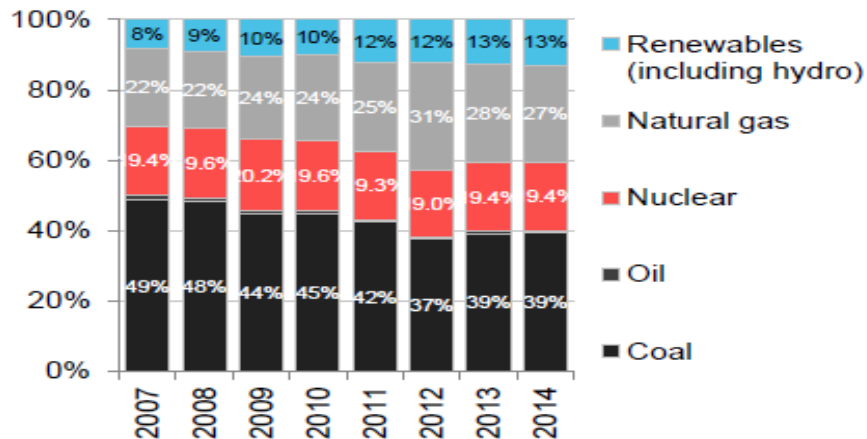
Source REN21 Renewables 2014 Status Report

[http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014\\_full%20report\\_low%20res.pdf](http://www.ren21.net/Portals/0/documents/Resources/GSR/2014/GSR2014_full%20report_low%20res.pdf)

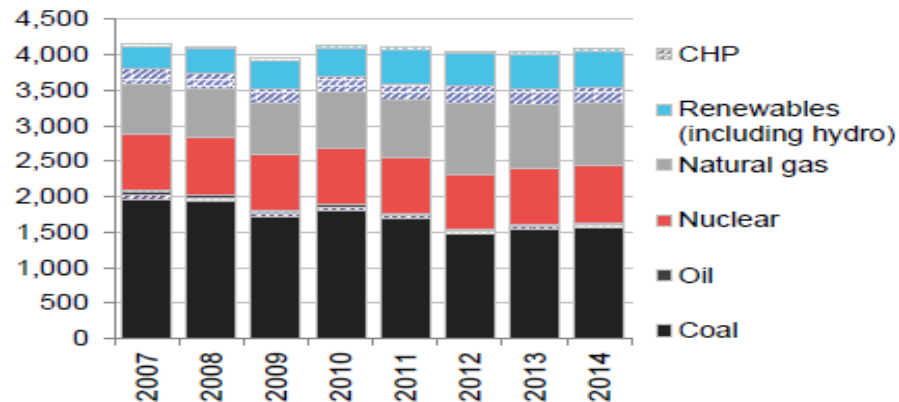


# U.S. Electricity Generation Mix

US electricity generation by fuel type (%)



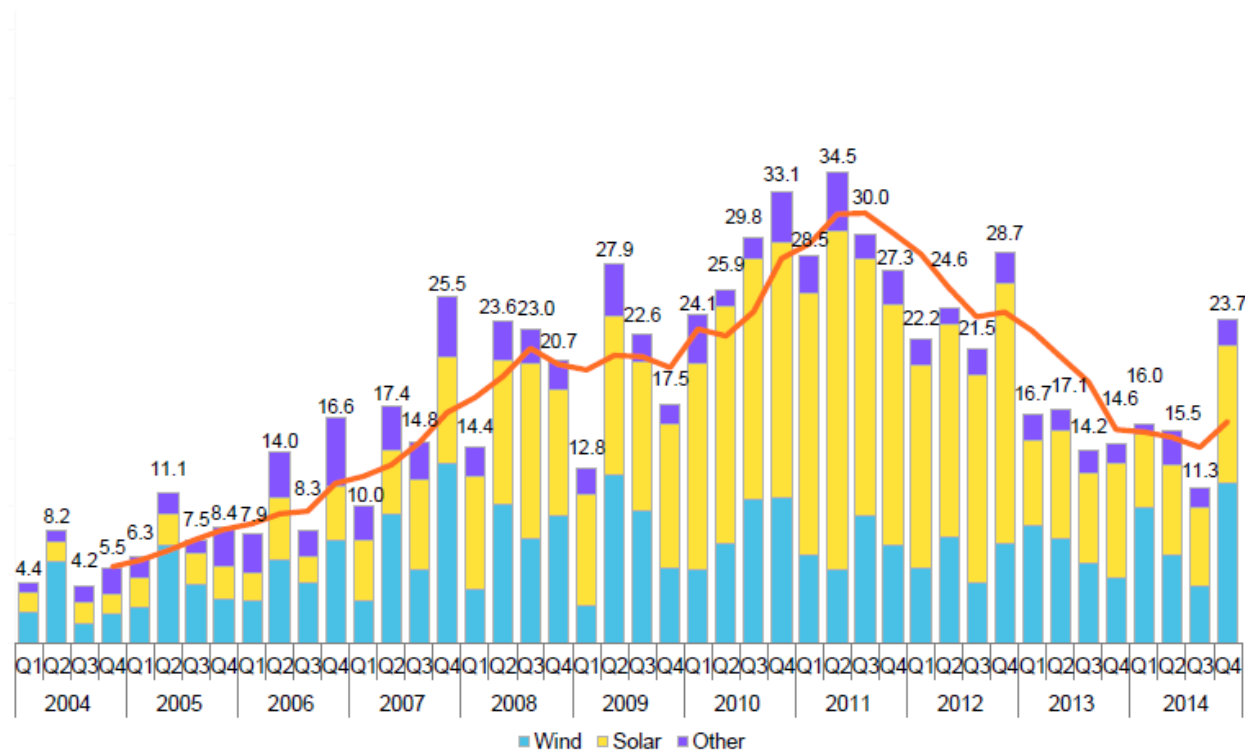
US electricity generation by fuel type (TWh)



Source: <http://www.bcse.org/images/2015%20Sustainable%20Energy%20in%20America%20Factbook.pdf>



# EMEA NEW INVESTMENT IN CLEAN ENERGY BY SECTOR Q1 2004-Q4 2014 (\$BN)

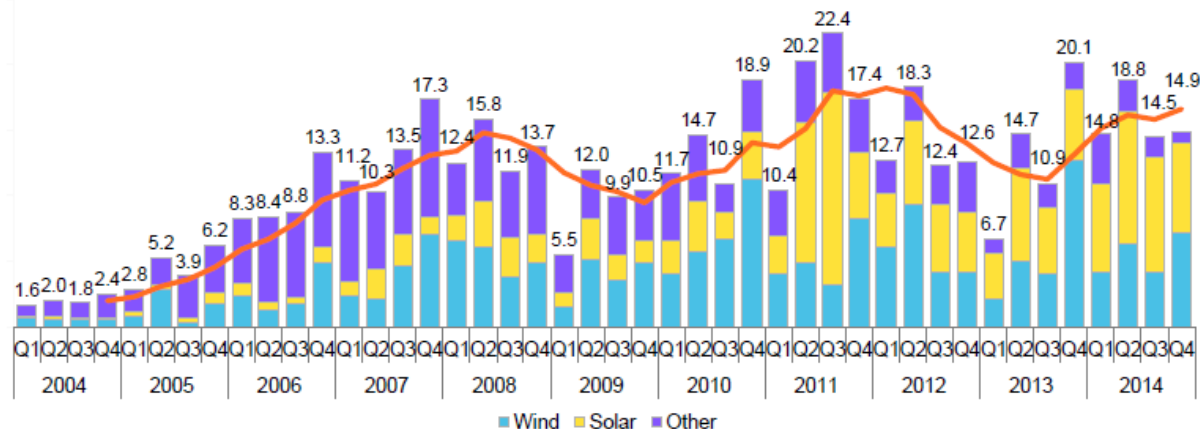


Note: Total values include estimates for undisclosed deals. Excludes corporate and government R&D, and spending for digital energy and energy storage projects (reported in annual statistics only).

Source: Bloomberg New Energy Finance

# AMER NEW INVESTMENT IN CLEAN ENERGY BY SECTOR Q1 2004-Q4 2014 (\$BN)

**Bloomberg**  
NEW ENERGY FINANCE



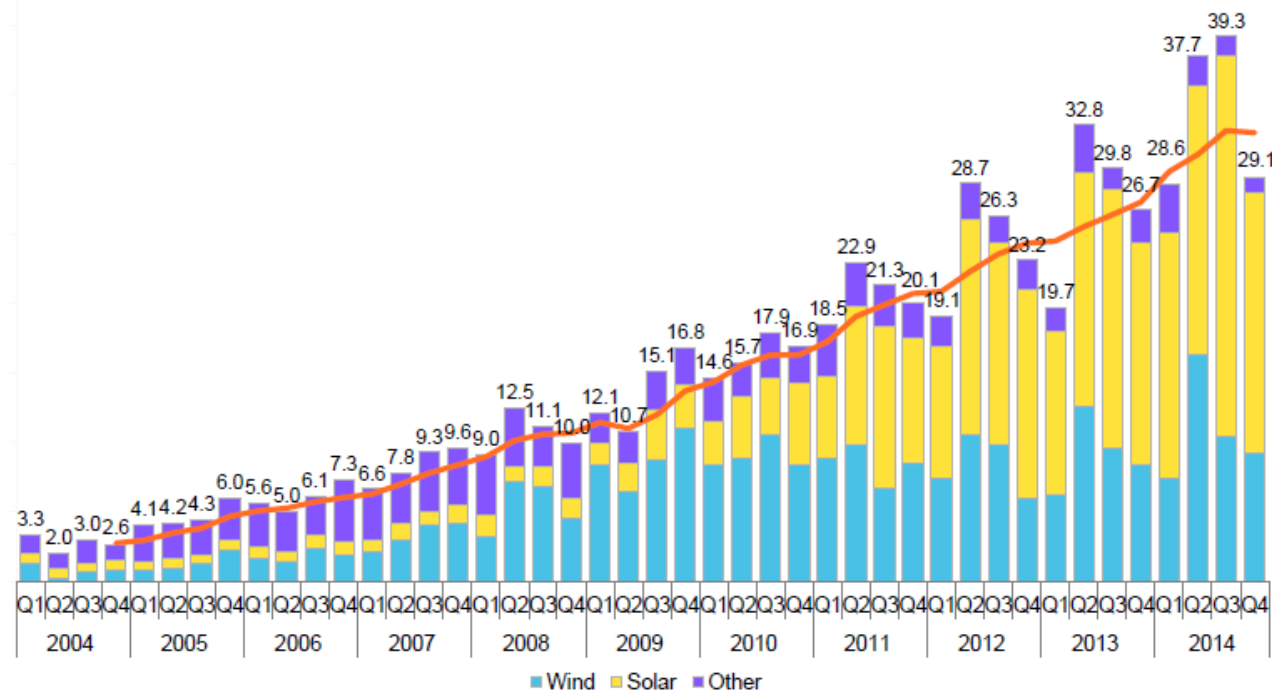
Note: Total values include estimates for undisclosed deals. Excludes corporate and government R&D, and spending for digital energy and energy storage projects (reported in annual statistics only).

Source: Bloomberg New Energy Finance

8 January 2015

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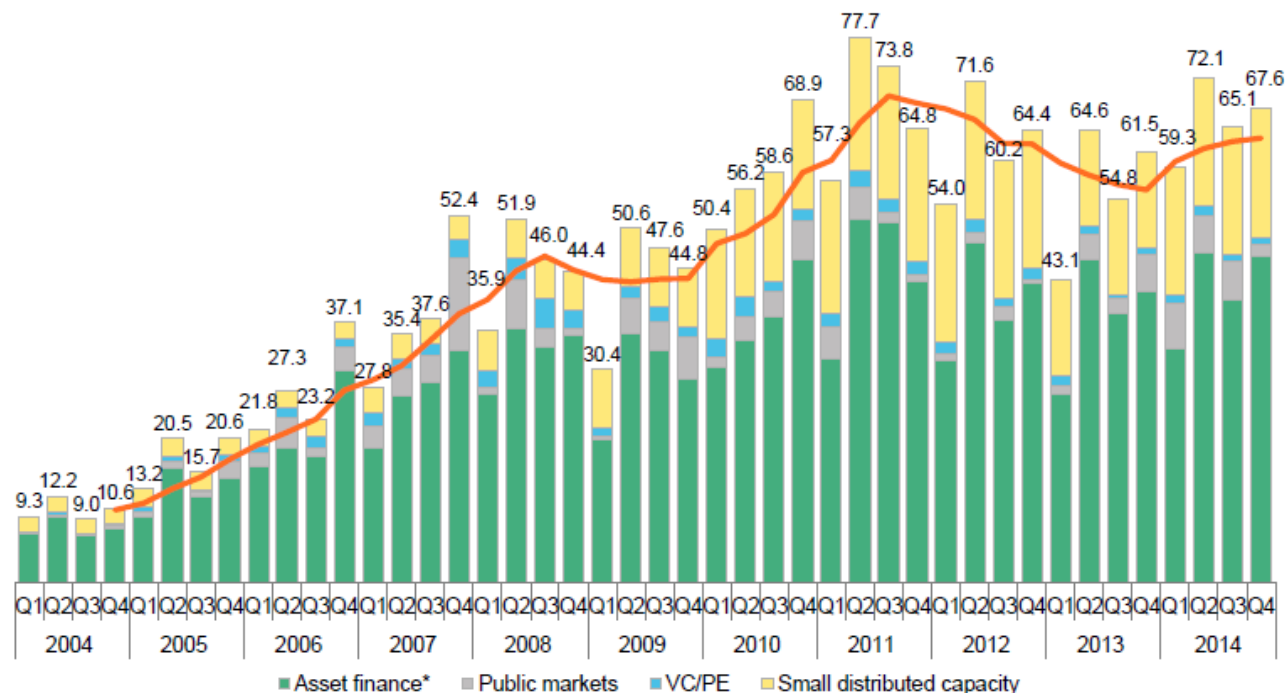
# APAC NEW INVESTMENT IN CLEAN ENERGY BY SECTOR Q1 2004-Q4 2014 (\$BN)



Note: Total values include estimates for undisclosed deals. Excludes corporate and government R&D, and spending for digital energy and energy storage projects (reported in annual statistics only).

Source: Bloomberg New Energy Finance

# NEW INVESTMENT IN CLEAN ENERGY BY ASSET CLASS Q1 2004-Q4 2014 (\$BN)



\*Asset finance adjusted for re-invested equity

Note: Total values include estimates for undisclosed deals. Excludes corporate and government R&D, and spending for digital energy and energy storage projects (reported in annual statistics only).

Source: Bloomberg New Energy Finance